Study of the Supernova Nuclear Reaction ^{40}Ca(α,γ)^{44}Ti in the Energy Regime Important for Nucleosynthesis ◇

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The ^{44}Ti ($t_{1/2}$=59 y) nuclide is considered an important signature of core-collapse supernova (SN) nucleosynthesis and has recently been observed as live radioactivity by γ-ray astronomy from the CasA SN remnant. We investigated in the laboratory the major ^{44}Ti production reaction, ^{40}Ca(α,γ)^{44}Ti (E_{cm} = 2.1 - 4.17 MeV) by off-line counting of ^{44}Ti nuclei using accelerator mass spectrometry. The nucleosynthesis ^{40}Ca(α,γ)^{44}Ti reaction was studied using the MP tandem accelerator of the MLL. In this experiment, the reaction was performed in specific energy intervals to determine high productive energy regions in the relevant astrophysical regime.

1. The Target Irradiation

The experimental method, developed in [1,2], consists of an activation of a ^{4}He gas target by a ^{40}Ca beam and implantation of recoil products in a forward-positioned catcher, Fig.1.

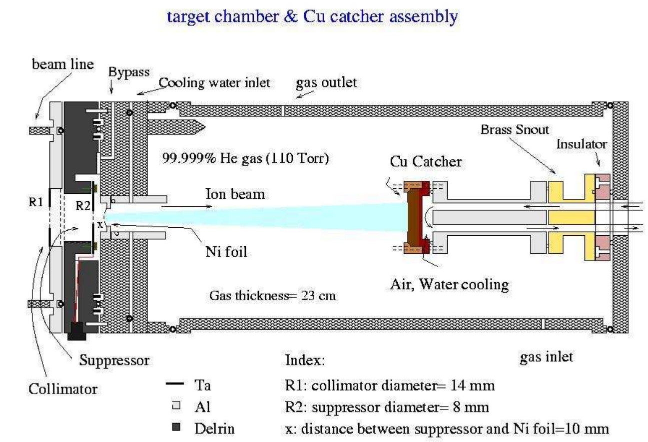

Fig. 1: Gas cell and catcher assembly used for the ^{40}Ca + ^{4}He activation at the MP Tandem accelerator. The cell was filled with He gas. The whole chamber assembly is electrically insulated and serves as a Faraday cup for beam charge integration.

^{44}Ti atoms are chemically extracted together with a ^{nat}Ti carrier by etching the catcher and separated by ion-exchange methods. The ^{44}Ti/Ti ratio (r_{Ti}) is then measured by accelerator mass spectrometry (AMS) in the range below 10^{-12} and the yield of ^{44}Ti nuclei produced in the activation (Y_{44}) is obtained from the relation $Y_{44} = r_{Ti} n_{Ti}$ where n_{Ti} denotes the number of atoms of ^{nat}Ti carrier used. Importantly, the derived yield Y_{44} is independent of chemical extraction efficiency or transmission losses during AMS analysis.

2. The AMS Measurement

After the irradiation and the chemical extraction of the produced ^{44}Ti the material is pressed into a sample holder for the AMS measurement in which the isotopic ratio ^{44}Ti/Ti is measured. The detection system is equipped with a Gas Filled Magnet System (GAMS, [3]) where the separation between the ^{44}Ti and its intensive isobar ^{44}Ca is excellent, Fig 2.

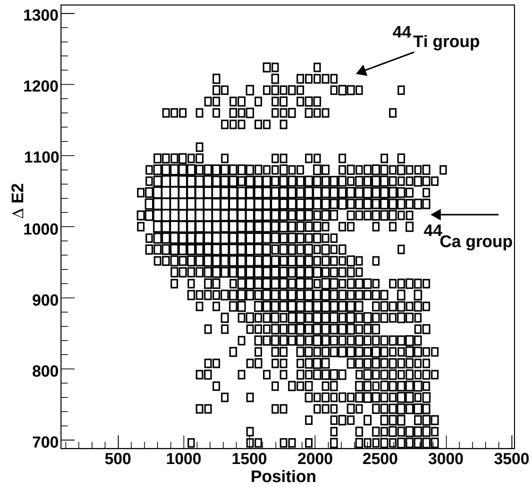

Fig. 2: Raw spectra of position versus one of the energy loss signals for one of the irradiated samples. Background can be completely suppressed with conditions on all 5 energy loss signals.

The ^{44}Ti yield $Y_{44} \propto (dE/dX)^{-1} \times \omega\gamma$, the stopping power and the resonance strength respectively, is used to determine the overall resonance strength $\Sigma\omega\gamma \propto \Gamma_\gamma \Gamma_\alpha / \Gamma_t$, proportional to the partial and the total widths of the energy levels, in the energy interval that was studied. This will be followed by the reaction rate calculation and the absolute yield of ^{44}Ti and comparing that to the observed values of the ^{44}Ti yield and the ratio ^{44}Ti/^{56}Ni observed in Cas A supernova. In this experiment, several irradiations were done in the range 2.1 - 4.17 MeV, important for nucleosynthesis, the same range as the previous experiment [4]. In addition, a further irradiation in the high energy regime (4.17 - 5.39 MeV) of ^{44}Ti was done. In this experiment, the total yield of the ^{40}Ca(α,γ)^{44}Ti reaction corresponds to an overall average resonance strength of about 150 eV, while the measured one in former experiments was 12 eV. This result is very important and might indicate that ^{44}Ti is produced more at higher temperatures during the supernova event. The measured yield ^{44}Ti/^{40}Ca of the reaction in this energy regime is $1.5\text{x}10^{-9}$. This yield will bring the experimentally measured values closer to the values inferred from astrophysical observations.

References

[1] M. Paul *et al.* Nucl. Phys. **A 718** (2003) 239c-242c
[2] S.K. Hui *et al.* Nucl. Instr. Meth. Phys. Res. **B 172** (2000) 642
[3] K. Knie *et al.* Nucl. Instr. Meth. Phys. Res. **B 172** (2000) 717
[4] H. Nassar *et al.* Phys. Rev. Lett **96** (2006) 041102

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